Schafer

Support to CBWCOM/Army CP-Lidar Program

February 1999

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Task Report – Naval Research Laboratory
Contract N00014-97-D-2014/001

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The tasking to Schafer Corporation from Edgewood Arsenal, the Army and CBWCOM Agent for this program was to assist them in developing and fielding seven (7), later reduced to six (6), eye-safe LIDAR units being developed by Schwartz Electro-Optics, Inc. of Orlando, FL and Fibertek, Inc. of Herndon, VA and designed to be mounted in Apache helicopters, The purpose of these units is to detect by light-scattering LIDAR technology low-lying (less than 2,000 feet) "clouds" of aerosols with a shape similar to a cigar. Such a cloud form would be expected from low-flying aircraft dispersal (e.g. a "crop duster") or a truck-mounted dispersal. It is assumed that innocent civilian activity with a similar resultant signature would not be occurring in a war zone. The particular issues on which Edgewood Arsenal requested that Schafer Corporation concentrate their technical efforts were centered on the laser radar, particularly the laser transmitter. The program is about 14 months over schedule at this time but nominally on current budget lines. This program has a relatively high visibility to the US Congress.

The original laser specification envisioned an ~ 100-watt average power 1J @100 Hz Neodymium: YAG laser, frequency-shifted to 1.54 microns in an optical parametric oscillator, producing ~ 50 watts of wavelength shifted output:

- The actual performance was considerably below this level;
- Additionally, optical damage was being found in the parametric oscillator KTA (potassium titanyl arsenate) crystals at levels well below those expected.

In late June, 1998 a meeting was held at Edgewood Arsenal to discuss the experimental results Schwartz and Fibertek has achieved up to that point, and the prognosis for meeting the specifications.

Actual progress on the program was hampered substantially by the failure of the sub-contractor, Recon Optical, Inc. to deliver an acceptable pointer/tracker. In addition to deficiencies in this area, lack of an acceptable pointer/tracker also stalled the Schwartz E-O effort to develop a the controller software (an estimated eight thousand lines of software to control the entire system). While some modules could be completed as independent units, without knowing what the hardware inputs would be, or the protocols, the higher level coding could not proceed.. The rather open-ended and unsatisfactory laser status at the end of June 1998 also left the outgoing signal strength as an unknown. There had also been earlier problems with the *Intevac* detectors, apparently caused by the spring 1998 floods in the vicinity of the contractor plant and poor local water quality. At the start of the Schafer tasking this latter issue was verging on successful resolution, so it was not an issue for our effort.

At the meeting at Edgewood in late June 1998, the laser problems were examined at some length. Briefly, they were that:

(1) Observed damage tracks and phenomenology are consistent with self-focusing and no other mechanism known to laser science.

(2) Observation by Fibertek that problem was occurring in Nd:YAG laser [occasional 'bright flashes'] suggests that while KTA crystals may exacerbate the problem [because of the high non-linear index of refraction,n_2], it is not new physics, but in fact a manifestation of self-focusing which was seen frequently in the 1960's and early 1970's when various organizations were trying to make powerful neodymium glass lasers for fusion.

The issue of the magnitude of the effect was raised. ***On the average,*** the cumulative self-focusing growth [the so-called "B-integral"] is only 10-20% of the size expected to cause a problem. But:

(1) A problem is that **the average doesn't count,** only the peak intensity reached on a particular shot. In the laser fusion context, laser repetition rates were ~ a shot per half hour or less. I think the NRL laser fusion group, had the "record" of >3,000 shots on target per year. The CP Lidar laser at 100 Hertz fires 6,000 shots per minute or more than 360,000 shots per hour or 8,640,000 shots per 24-hour day of

operation. This latter figure approximates the MTBF often assigned to very good MIL-SPEC laser range-finders/target designators.

(2) The briefing material doesn't give cavity lengths, but, from the 25 nsec pulsewidth, it would be reasonable to assume a value of 50 cm for the effective cavity length. The cavity mode spacing is then [_k =[1/2L] = 1/100 cm^{-1} or 0.01 cm^{-1}. At one micron, one Angstrom equals one cm^{-1}, so there will be about 100 axial modes per Angstrom of linewidth. A q-switched Nd:YAG laser typically has a [multi-mode, un -narrowed] linewidth of ~1 Angstrom. This linewidth equates to a coherence length of ~20 picoseconds. With this number of modes, it is possible for the "worst case" configuration [all modes exactly in phase] to give a peak power of 10^2 times the average. [This case is identical to a fully mode-locked case and demonstrates why mode-locking is such a powerful techniques for power enhancement!]. This makes it a pretty risky approach to use a non-controlled oscillator, especially at a high repetition rate. Sooner or later, <u>mode combinations which give rather high instantaneous peak powers will occur.</u>

(3) When people were involved in designing and building fusion lasers, they couldn't abide the uncertainty which a non-mode controlled oscillator would lead to, let alone the cost of damaged optics. In order to prevent this oscillators were designed that cleanly mode locked almost 100% of the time. Here you have the inverse problem. A solution which should certainly work, at least in principle, is to make the oscillator single frequency mode all of the time. The only reason for not unambiguously recommending this is that it may or may not be not be so easy or inexpensive to do; but it will certainly not be a quick thing to do, and the program is already well over schedule. More to the point would seem to be approaches that would fix the equipment already in hand to minimize the risk of further damage occurring.

Subsequent to this meeting, the suggestions that the program should proceed as if this were self-focusing was followed up on by Fibertek and Schwartz E-O. The proposal from the contractors Fibertek and Schwartz, in response to this recommendation, as reported at the 12-13 August meeting at Schwartz EO in Orlando, FL was that they would engage in the following activities during the planned experiments at Fibertek in the 17-28 August period:

(1) Testing of the laser with bandwidth-limiting etalons;

(2) Additional OPO testing with laser at nominally 60 watt level.

Additionally, the contractors claimed that in studying the laser performance after the June meeting with the oscillator output turned down to ~14 watts [versus 25 watts, nominal] , the incidence of pulses where there was any flash of light [i.e. "evidence of self-phase modulation] had declined to ~ one every few minutes, rather than ~ one, or more, per second. This had reduced the incidence of anomalous pulses by a factor of approximately 1,000, i.e. to a point where they felt that this was not an operational problem, at least at OPO outputs of 20-25 watts at 1.55 microns. In considering this contention, Schafer feels that there is some truth to their observation. At the time Schafer observed tests ongoing at Fibertek in late August, Fibertek and Schwartz had run the OPO for more than 10 hours quasi-continuously [i.e. over two working days] without seeing any evidence of systematic crystal or performance degradation. Clearly, the contractors would like to claim the non-linear optics/damage problem is solved, at least for the first two units, and they may be correct in a pragmatic if not a literal sense.

For these tests in July , as well as those done shortly before the mid-August review, Fibertek had implemented the earlier suggestion of improving the "staging" by reducing the oscillator but keeping the amplifiers at full gain. Before the August review this was done by attenuating the oscillator output by a wave plate-polarizer combination. More recently, Fibertek has tuned the oscillator to operate at a lower output, ~14 watts versus 25 watts. It was also claimed that under these conditions the :"testers" "rarely" saw any light flashes from the laser. This re-tuning could bring two benefits: in addition to improved staging reducing the net self-focusing" gain coefficient, this change could actually improve the anomalous laser pulse statistics, on its own. The reason this is true is that going to slightly (~30%) lower gain, as evidenced by a 30% longer pulse-width, can actually lead to a more than 30% increase in the pulse buildup time. For the cited laser parameters, lengthening the pulse buildup time by almost 2x, in terms of cavity transits after the q-switch opens could give a reduction of the linewidth to < 70% of the line-width at 25 watts. This would in turn give a reduction in the incidence of anomalous pulses of more than 30% since one you wins twice: first by reduction in the number of oscillating longitudinal modes by 30%; secondly by the convolution of the lengthened buildup time with the distribution function. If previously, 1% of the pulses were dangerous, now it will be a much smaller fraction. The "eyeball" estimate seems to be that "flashes" occur now at intervals of 10's of seconds, versus almost continuously before.

In August, when Schafer visited Fibertek on the 27th, we were shown the laser and OPO setup in the lab. Their statements at the review seemed to accurately represent the achieved statistics. Additionally, Fibertek pointed out that if the solution was to restrict the laser bandwidth even further, they had a problem in terms of no reliable diagnostics for spectrally narrow, but temporally "spiky" outputs, which was a lack of ultra-high resolution capability. Is the problem totally solved? Not really, and at some later date it could return. But, at the present time, this is probably not the leading issue for the laser, or for getting the system out into the field.

The leading issue for the laser is the SDL diode lifetime and efficiency. Fibertek personnel were concerned with SDL's Option #1 in that it would force them to overdrive their (i.e. Fibertek's) laser diode power supplies at or above 90 amps. That is, while this choice might solve the SDL problem, it could create a Fibertek problem. I think on this one I would defer to Fibertek, as what SDL will achieve is somewhat open, Fibertek should know their own power supplies. From Ralph's point of view, Option #1 runs the risk of rousing the devil they do know, while option #2 will not make any current technical problems worse. Option #2 as presented by SDL does, however, raise a concern about schedule. What probably should be done is the following plan of action:

(1) Pursue option #2, but make it clear that progress is being actively tracked by CBW-COM and not just by Schwartz and Fibertek;

(2) For now, I think we need to put the self-focusing problem to bed as "solved well enough for the moment", at least for operation at a 2—25 watt OPO output.

(3) Fibertek and Schafer personnel have discussed how one might implement a compact multi-mode "seeder" laser using a thin etalon of Nd: YAG. This probably could be made to work within the limits of the present package. Rather than doing this now, it would seem more prudent to make this part of the improvements which get done to units 3-6, to make them really "bulletproof".